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PATENT SPECIFICATION

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COMPLETE SPECIFICATION.

Improvements in or relating to Jet Noise Suppression Means.

We, GEOFFREY MICHAEL LILLEY, M.Sc., D.I.C., A.F.R.A.E.S., ROBERT WESTLEY, B.Sc., D.C.A.E., and ALEC DAVID YOUNG, M.A., F.R.A.E.S., all British Subjects, and all of The College of Aeronautics, Cranfield, Bletchley, Buckinghamshire, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement :—

This invention is concerned with noise suppression of jets issuing from nozzles. The term "jets" is intended to be broadly interpreted to include such examples as steam jets, air jets from safety valves of high pressure air tanks and propulsive jets for vehicles, aircraft and ships.

The particular instance of the noise created by the propulsive jet of an aircraft rocket, ramjet or gas turbine engine is one which is now well to the fore. Such a jet diverges in mixing with the atmosphere, the angle of divergence being dependent on the ratio of the pressure at the nozzle exit to the atmospheric pressure. When the jet exit velocity is greater than sonic velocity a train of shock waves will exist in the jet. The noise suppression means forming the subject of the present invention is applicable in cases where shock waves do and do not appear in the jet.

It will be appreciated that when a jet emerges into the atmosphere from an aircraft jet engine there is a steep velocity gradient across the boundary of the jet. This is however only an extreme example of the general case of a jet issuing into an ambient gaseous fluid. It can be shown theoretically that the intensity of noise produced by a jet is closely associated with this velocity gradient. If the velocity of the gases leaving a jet engine is

substantially reduced then the noise created by that engine may therefore be expected to be much less than with a comparable engine having a greater jet velocity. The velocity gradient could, on the same basis, also be reduced by spreading out a jet more rapidly than the normal divergence provides, i.e. by increasing the mixing region between the issuing jet and the ambient gaseous fluid. It will be appreciated that as a jet emerges from a nozzle say into the atmosphere the periphery of the jet begins to mix with the atmosphere. The extent of mixing increases with distance from the nozzle until finally the whole jet is affected. In an intermediate stage, downstream of a circular nozzle, for example, there is, as it were, an "umbra" or convergent conical core of unmixed jet and a "penumbra" of divergent conical shape where mixing is occurring.

Experimental evidence has now been accumulated by the applicants which supports these theoretical deductions. Thus it has been found that the sound field produced by a jet is largely caused by the strong vorticity existing in the flow near to and beyond the nozzle exit. Thus, the coupling of eddying flow and large velocity gradients, whether lateral as in the mixing region of the jet, or longitudinal as across shock waves, has been found to give rise to intense noise. The sound field displays directional properties the character of which varies with the frequency of the noise produced and the jet speed at the nozzle exit.

The invention provides a noise suppressing jet nozzle in which continuously effective means are provided at or adjacent to the nozzle exit for modifying the boundary of an issuing jet in such manner that the mixing region between that jet and the ambient gaseous fluid is increased compared with the corresponding region for a plain nozzle exit.

Noise suppression with embodiments of the invention has been carried out in model and full scale tests, an average reduction of approximately ten decibels over the audio frequency range having been achieved with one gas turbine jet engine. With an engine producing a noise intensity of about 130 decibels above the threshold of audibility such a reduction has considerable utility. The unsuppressed engine creates a noise which is extremely distressing to a human being at a distance of a hundred feet from the nozzle exit and which is, moreover, capable of causing such structural vibration that fatigue failure may become a real danger. A similar engine to which an embodiment of the present invention has been applied is noticeably quieter, causes no such distress and is expected largely to reduce the vibrational fatigue problems. The embodiment mentioned comprises the provision of tooth-like projections extending in the general direction of the issuing jet beyond the nozzle exit. It has been found preferable for one or more of such tooth-like projections to protrude into the jet, for example by being inclined inwards at an angle of approximately 30° to the jet direction.

With the toothed nozzle aircraft jet engine tested, the issuing jet is found quickly to enlarge to a larger envelope than the nozzle circumference and thus there is rapid extension of the mixing region between the jet and the atmosphere. Approximate figures for the spread of the jet in this case are to an overall diameter of about 4D at a distance 5D downstream of the nozzle exit and nearly 5D at a distance 10D downstream of the nozzle exit, where D is the nozzle diameter. Without the noise suppressing nozzle, that is, with a plain circular nozzle, the corresponding figures were just less than 2D and 3½D respectively.

Various shapes and arrangements of teeth are possible and some may be made adjustable. A variable area nozzle effect may be produced with adjustable tooth-like projections.

Apertures distributed around the perimeter of the nozzle upstream of the exit thereof may have similar effect to the extending teeth. Another alternative embodiment, which is at present considered to be specially suitable for the choked nozzle case, has a finely perforated nozzle wall immediately upstream of the main exit. For the same case, a diffuser extension, into the upstream end of which the nozzle proper protrudes, may be appropriate.

A noise suppressing device, having the effect of increasing the mixing region as stated above, may be separately fabricated and attached to or associated with a jet nozzle. The invention will now be described, by way of example only, with reference to a

number of embodiments thereof, shown in the accompanying drawings in which:—

Figures 1 to 12 show a number of nozzle exit tooth-like projection configurations for suppression of jet noise, these being primarily arranged for nozzles of jet propulsion engines.

Figure 13 shows a tooth-like projection arrangement which is supported independently of the nozzle exit.

Figure 14 shows an application of the invention to a jet engine propulsion nozzle equipped with an 'eyelid' type variable area nozzle.

Figure 15 shows a ring of tooth-like projections for attachment to a jet nozzle for noise suppressing purposes.

Figures 16 and 17 show the operation of an independently supported noise suppressor downstream of a nozzle exit.

Figure 18 shows an apertured jet nozzle with a sliding obturator mechanism.

Figure 19 shows a jet nozzle having a finely perforated wall upstream of the nozzle exit.

Figure 20 shows a noise suppressor nozzle exit from a convergent/divergent nozzle.

Figures 21 and 22 show arrangements of a diffuser extension to a jet nozzle which are particularly suitable for noise suppression of a choked nozzle.

Turning first to Figure 1, the downstream end of the jet pipe of a gas turbine jet propulsion engine is shown. The pipe terminates in a convergent part 2 and a nozzle exit shown at 3. Whereas the normal and conventional jet pipe orifice is a plain circular one it will be noticed that in this case there is provided a number of tooth-like projections 4 distributed around the perimeter of the nozzle exit. They extend in the general direction of the issuing jet and have the effect of modifying the boundary of that jet so that the mixing region between the jet and the atmosphere is extended compared with the corresponding region in the absence of the tooth-like projections. It will be noticed that the six tooth-like projections shown are all bent slightly inwards towards the axis of the jet. This has been found to be a satisfactory way of decreasing the jet noise but it does also somewhat decrease the effective nozzle exit area. This may unsatisfactorily increase the jet pipe temperature and a compromise may have to be resorted to. One such compromise is shown in Figure 2 in which the arrangement is generally similar but that some of the tooth-like projections 4 are extending downstream parallel to the jet axis whilst others are inclined a little away from that axis. The two kinds of tooth-like projections are arranged alternately around the perimeter of the nozzle exit. It will be noticed that the tooth-like projections 5 are inclined outwards whilst the

remaining tooth-like projections 4 are parallel to the jet axis. In another alternative arrangement all the tooth-like projections are parallel to the jet axis, and the opportunity is taken in Figure 3 to show that all these tooth-like projections need not necessarily be of the same length. The tooth-like projections 6 in this instance are double the length of the remaining tooth-like projections 4. The advantages of one configuration of tooth-like projections over another in any particular circumstance depends upon the nozzle exit size and shape and the jet velocity for that particular application. Also the number of tooth-like projections may be varied to suit particular circumstances. In Figures 4 and 5 there are shown two arrangements in which six tooth-like projections in line with the issuing jet axis are proposed. In the Figure 5 arrangement a shroud 7 has been added to the downstream tops of the tooth-like projections 4 mainly for the purpose of increasing the mechanical strength of the tooth-like projections. One effect of this is to transfer the nozzle exit to a plane slightly downstream of its original position. Upstream of that new position there are then a number of apertures 8, being the spaces between the tooth-like projections, distributed about the perimeter of the nozzle. In Figure 6 there is shown an arrangement that has proved to be extremely satisfactory in full scale tests upon a gas turbine jet propulsion engine. In this instance three of the tooth-like projections 4 at 120° intervals around the perimeter of the nozzle exit are in line with the issuing jet axis whilst the remaining tooth-like projections 9 making up a symmetrical arrangement are inclined in towards the jet axis at an angle of approximately 30° .

In the Figures 7 to 13 there are shown various other configurations of tooth-like projections which are proposed for the purpose of noise suppression of jets. The tapering tooth-like projection construction is shown in Figure 7 in which the tooth-like projections 10 increase in width as they extend away from the nozzle exit. These tooth-like projections are shown all to be slightly bent in towards the jet axis. In Figure 8 the tooth-like projections 11 each take a fluted shape at their downstream ends. In Figure 9 the tooth-like projections 12 have a generally circular arc cross section at their upstream ends and a right angled section at their downstream ends. The effect of this is to modify the effect of the circular nozzle exit 3 and to provide for the main part of the issuing jet a square formation due to the four angled ends of the tooth-like projections 13.

The tooth-like projection constructions so far described have all had tooth-like projections extending away from the nozzle exit in a general plane of the pipe of which they have formed a continuation. In Figures 10

and 11 radial tooth-like projections 14 are proposed and these have modified downstream ends which have the effect of imparting swirl to the outer regions of the issuing jet. In Figure 10 it will be noted that the downstream ends of the radial tooth-like projections 14 are curved as shown at 15. In Figure 11 the downstream ends of the radial tooth-like projections 14 are twisted as shown at 16 into planes generally tangential to the jet boundary.

In all of the constructions shown up to now there have been spaces between adjacent tooth-like projections at the nozzle exit boundary. There are no such spaces in the construction shown in Figure 12. Tooth-like projections are arranged continuously around the perimeter of the nozzle exit occupying the whole of that perimeter. Twelve tooth-like projections are shown of which alternate ones 17 are inclined outwards away from the jet axis and the intervening ones 18 are all inclined towards the jet axis.

In some applications it may not be desirable to have the means for increasing the mixing region fixed to the jet nozzle exit or even attached thereto. In Figure 13 therefore the arrangement is indicated of a separately mounted noise suppressor associated with the jet nozzle exit 3 but situated some way downstream thereof. A ring 22 conforming generally to the boundary of the issuing jet is supported upon struts 23 independently of the jet pipe 1. The downstream side of the ring 22 is equipped with tooth-like projections 24 which correspond generally with the tooth-like projections in Figure 1. The effect is similar in that the issuing jet after passing through the ring 22 has its mixing region thereafter considerably extended by the provision of the tooth-like projections and this has the desired noise suppressing effect.

In Figure 14 the application of the present invention to the case of a gas turbine jet propulsion engine equipped with a variable area nozzle of the eyelid or clam shell type is shown. The jet pipe 1 can be seen enclosed within a nacelle 25. The nozzle exit 3 is equipped with two tooth-like projections in diametrically opposite positions these tooth-like projections extending in the direction of the nozzle, that is being inclined inwardly slightly towards the jet axis due to the convergence of the nozzle at its exit.

The eyelid shutters 26 are shown in their retracted position between the convergent nozzle 2 and the nacelle 25. The downstream edges of these shutters have inwardly inclined tooth-like projections 27 for noise suppression. The shutters are pivotable about the bearings 28 in conventional fashion for such shutters. The actuating mechanism is also conventional and is not shown. It will be understood that the tooth-like projections

4 and 27 co-operate to increase the mixing region for an issuing jet compared with a normal variable area nozzle of this type.

Although the majority of the preceding constructions have shown jet nozzles with tooth-like projections which are integral structures with the jet pipe itself the noise suppression device may be separately made and fitted to a conventional nozzle. Such an attachable noise suppression device is shown in Figure 15. The arrangement has an effect similar to that of the Figure 6 construction for six tooth-like projections are provided, three of which are inwardly inclined compared with the mounting ring 29. This ring is split and may be easily fitted on to a conventional jet nozzle. If that nozzle is convergent at its exit the ring 29 can be constructed with a base diameter greater than that at the bottom of the tooth-like projections so as to have a similar convergence. The tooth-like projections 4 and 9 may be unitary with the ring 29.

Figures 16 and 17 illustrate a more complicated arrangement of tooth-like projections for fitting downstream of a jet nozzle exit. There will be seen a number of tooth-like projections 30 each pivoted about its mid point and mounted upon a ring 31. This ring is supported independently of the jet nozzle by struts 32. The controlling mechanism for two of the tooth-like projections are shown as pivoted links 33 and 34. The link 33 is attached to a downstream end of its tooth-like projection whilst the link 34 is attached to the upstream end of its tooth-like projection. Simultaneous movement of these links, 33 to the right and 34 to the left, cause the respective tooth-like projections to be inclined towards and away from the jet axis. Alternate tooth-like projections are connected to mechanisms operating as those just described so that after operation the tooth-like projections are as shown in Figure 17. In an alternative construction all the tooth-like projections 30 may have their downstream ends inclined inwardly towards the jet axis.

A noise suppressing jet nozzle arrangement without tooth-like projections is shown in Figure 18. In this instance there are a number of apertures 35 around the perimeter of the convergent part 2 of the nozzle and these allow the boundary layer of the jet to escape and mix with the atmosphere. The effect is much like that of the Figure 5 construction but there are more and smaller apertures upstream of the nozzle exit 3. A variable exit area effect may be achieved through operation of the slidable obturator elements 36, whose fully closed position is shown dotted. The elements 36 have flanges 37 which are preferably slidably mounted on the inside wall of a nacelle surrounding the jet pipe.

The noise suppression arrangement shown in the remaining Figures 19 to 22 have been particularly designed for use with choked nozzles, that is those in which supersonic exit velocities are achieved. In such cases there is a pressure difference available between the jet as it reaches the nozzle exit and the surrounding gaseous fluid, i.e. the atmosphere in the case of a jet propulsion engine. In the embodiment of Figure 19 that pressure difference is made use of to cause the boundary layer of the jet to pass outwardly through the finely perforated or gauze wall 38 immediately upstream of the nozzle exit 3. That spread outwardly of the jet both reduces the pressure difference at the nozzle exit 3 and enables more speedy mixing with the atmosphere to take place. The shock waves downstream of the exit 3 are appreciably lessened in intensity.

The arrangement shown in Figure 19 has an obturator element 39 slidably mounted over the downstream end of the jet pipe, the edge of which can be seen at 40. The obturator element normally lies within the nacelle 41. In its fully extended position, indicated by the dotted lines 42 the perforated wall 38 is closed. It is probably desirable for high speed flight to extend the obturator not only because noise suppression is less necessary but also in order to reduce drag.

A more conventional supersonic nozzle is of convergent/divergent construction and such a nozzle is indicated by dotted lines 43 in Figure 20. The throat construction is contained within a nacelle 44. It will be seen that the outlet end 3 of this nozzle is able to be usefully equipped with noise suppressing teeth 4 as in previous arrangements.

Another nozzle arrangement suitable for choked flow is indicated in Figure 21. In this construction a conventional jet pipe 1 with convergent portion 2 leads to the usual nozzle exit at 3. This exit 3 is however positioned so that it protrudes into a divergent extension piece 45, a gap 46 being left between the perimeter of the nozzle exit 3 and the inner wall of the diffuser extension 45 in the plane of the nozzle exit. The choked flow issuing from the nozzle exit 3 tends to extend its boundary to coincide with the inner wall of the diffuser extension just downstream of the exit 3. This results from the pressure difference between the issuing flow and the air trapped in the re-entrant between the nozzle and the diffuser. Providing the diffuser is not of too large a cone angle in the divergent direction the flow stays circumscribed by the diffuser wall and the mixing region of the jet issuing from the downstream end 47 of the diffuser extension is greater than would normally have been attained because of the effect of the nozzle exit inside the diffuser. In addition the shock

waves of the emerging jet are lessened in strength because of the permissive expansion of the flow area within the diffuser.

The noise reduction effect of the Figure 21 arrangement can be increased by the provision of teeth of the general kind described above either at the extension edge 47 or at the nozzle exit 3 or at both positions. The latter possibility is illustrated in Figure 22.

In this figure the diffuser extension 45 has a double wall construction, the inner wall 48 being perforated and the space between the two being filled with sound insulation material.

Although in the embodiments of the invention described above the nozzle exit has been circular, the invention is applicable to nozzle exits of other shapes. For example slot nozzles have been previously proposed as have other plain nozzles of other shapes, there is no reason to say that the invention will not be usefully applied to any shape of nozzle exit. Moreover the fact that the embodiments have particularly related to gas turbine jet propulsion engine nozzles is not to be considered as limiting the application of the invention to that special case of a noisy jet, important though noise suppression is in that instance. It has already been stated that the noise field is directional and in some instances therefore the device adopted for noise suppression may be deliberately constructed to have an asymmetric effect. In this respect the frequency spectrum pattern may be just as important as the general noise level contours. For example it may be desirable to keep a noise of a certain frequency away from particular parts of an aircraft structure. This can be done by the use of the present invention. Embodiments of this invention, whilst being capable of reducing the general level of noise over the audio frequency range may actually increase the noise attributable to a restricted frequency range. This may sometimes be desirable, for instance with jet aircraft propulsion engines a tooth-like projection construction noise suppression device may increase comparatively high frequency noise but with the considerable compensation of reducing noise in lower frequencies which is generally more distressing and less readily attenuated with distance.

In discussing the tooth-like projection embodiments of the invention above, in most cases the tooth-like projections illustrated have been rectangular in shape. It will be understood however that tooth-like projections of other shape may be employed providing they extend the mixing region between the jet and the ambient gaseous fluid in the desired manner. Where a tooth-like projection ring is associated with the jet nozzle and positioned just downstream of the nozzle exit, as is the case with Figure 14, the

tooth-like projections might be mounted on the upstream side of the ring. Such tooth-like projections would still extend in the general direction of the issuing jet and it is desired to make clear that it is not essential that the tooth-like projections should have their bases at their upstream ends.

What we claim is:—

1. A noise suppressing jet nozzle in which continuously effective means are provided at or adjacent to the nozzle exit for modifying the boundary of an issuing jet in such manner that the mixing region between that jet and the ambient gaseous fluid is increased compared with the corresponding region for a plain nozzle exit.
2. A noise suppressing jet nozzle as claimed in Claim 1 in which said jet modifying means comprises tooth-like projections extending in the general direction of the issuing jet beyond said exit.
3. A noise suppressing jet nozzle as claimed in Claim 2 in which at least one of said tooth-like projections protrudes into said issuing jet.
4. A noise suppressing jet nozzle as claimed in Claim 3 in which there is an even number of said tooth-like projections symmetrically distributed around the perimeter of said nozzle exit, alternate tooth-like projections protruding into the issuing jet.
5. A noise suppressing jet nozzle as claimed in Claim 3 or 4 in which the or each protruding tooth-like projection is inclined inwards at an angle of approximately 30° to the direction of the issuing jet.
6. A noise suppressing jet nozzle as claimed in Claim 3 or 4 in which the or each protruding tooth-like projection is retractable whereby the effective cross sectional area of the nozzle exit may be varied.
7. A noise suppressing jet nozzle as claimed in Claim 3 or 4 in which the or each protruding tooth-like projection is angularly adjustable.
8. A noise suppressing jet nozzle as claimed in Claim 2 in which said tooth-like projections are twisted along their length.
9. A noise suppressing jet nozzle as claimed in Claim 2 in which said tooth-like projections are rectangular in shape.
10. A noise suppressing jet nozzle as claimed in Claim 2 in which said tooth-like projections are fluted along their length.
11. A noise suppressing jet nozzle as claimed in Claim 2 in which said tooth-like projections also extend normally into said issuing jet.
12. A noise suppressing jet nozzle as claimed in Claim 2 in which some at least of said tooth-like projections are connected together at or near their ends remote from the nozzle exit.

13. A noise suppressing jet nozzle as claimed in Claim 2 in which some at least of said tooth-like projections form part of the downstream end of jet spoiling means operable to change the effective cross sectional area of the nozzle exit.

14. A noise suppressing jet nozzle as claimed in Claim 2 in which said tooth-like projectors are of different lengths.

15. A noise suppressing jet nozzle as claimed in Claim 2 in which at least one of said tooth-like projections is inclined away from the issuing jet.

16. A noise suppressing jet nozzle as claimed in Claim 1 in which said jet modifying means comprises a number of apertures distributed around the perimeter of said nozzle immediately upstream of the exit thereof.

17. A noise suppressing jet nozzle as claimed in Claim 1 in which said jet modifying means comprises a finely perforated wall to the nozzle immediately upstream of the exit thereof.

18. A noise suppressing jet nozzle as claimed in Claim 16 or 17 and comprising a modification to the continuous effectiveness of the mixing region increasing means in the provision of an adjustable obturating means on the outside thereof by means of which said apertures or perforations may be opened and closed at will.

19. A noise suppressing jet nozzle as claimed in Claim 1 in which said jet modifying means comprises a diffuser extension into the upstream end of which the nozzle exit proper protrudes so that there is a gap between the perimeter of the nozzle exit and the diffuser wall in the plane of the nozzle exit and a re-entrant therebetween upstream of the exit.

20. A noise suppressing jet nozzle as claimed in Claim 19 in which teeth extending in the general direction of the issuing jet are fitted to the downstream end of said diffuser extension.

21. A noise suppressing jet nozzle as claimed in Claim 19 in which teeth extending in the general direction of the issuing jet are fitted to the nozzle exit proper within said diffuser extension.

22. A noise suppressing jet nozzle as claimed in Claim 19 in which said diffuser the inner one of which is perforated, the space within the double wall being filled with sound insulating material.

23. A noise suppressing jet nozzle as claimed in any one of the Claims 1 to 22 in which said nozzle exit is circular.

24. A noise suppressing device for attachment to a jet nozzle and which has the continuous effect of increasing the mixing region between an issuing jet and the ambient gaseous fluid compared with the correspond-

ing region for said nozzle without said device attached thereto.

25. A noise suppressing device as claimed in Claim 24 which comprises a number of tooth-like projections arranged to extend in the general direction of an issuing jet when said device is attached to the nozzle.

26. A noise suppressing device as claimed in Claim 24 which comprises a finely perforated extension piece arranged to fit on to the nozzle thereby extending the exit proper therefrom downstream.

27. A noise suppressing device as claimed in Claim 24 which comprises a diffuser extension arranged to fit over the nozzle so that the latter protrudes into the upstream end of said extension.

28. A jet propulsion engine nozzle equipped with continuously effective noise suppression means which modify the boundary of an issuing jet in such manner that the mixing region between that issuing jet and the surrounding atmosphere is increased compared with the corresponding region for a plain nozzle exit.

29. A jet propulsion engine nozzle equipped with a number of tooth-like projections distributed around the periphery and extending in the general direction of an issuing jet, the tooth-like projections being so constructed and arranged as to effect an appreciable reduction in total intensity of jet noise compared with a conventional jet nozzle.

30. A noise suppressing jet nozzle with tooth-like projections substantially as described and as shown in any one of the Figures 1 to 4, 6 to 12, 14 and 20 of the accompanying drawings.

31. A finely perforated noise suppressing jet nozzle substantially as described and as shown in Figure 19 of the accompanying drawings.

32. An apertured noise suppressing jet nozzle substantially as described and shown in Figure 5 or 18 of the accompanying drawings.

33. An extended diffuser noise suppressing jet nozzle substantially as described and shown in Figure 21 or 22.

34. A device for association with a jet nozzle for jet noise suppression substantially as described and as shown in Figures 13 or 15 or 16 and 17 of the accompanying drawings.

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PROVISIONAL SPECIFICATION.

Improvements in or relating to Jet Noise Suppression Means.

We, GEOFFREY MICHAEL LILLEY, M.Sc., D.I.C., A.F.R.A.E.S., ROBERT WESTLEY, B.Sc., D.C.A.E., and ALEC DAVID YOUNG, M.A., F.R.A.E.S., all British Subjects, and all
 5 of The College of Aeronautics, Cranfield, Bletchley, Buckinghamshire, do hereby declare this invention to be described in the following statement:—

10 The present invention is concerned with the reduction in noise from a jet or rocket exhaust nozzle the exhaust gases from which discharge into the atmosphere. The word "jet" is for the purpose of the present invention broadly used and may be said to include
 15 steam jets from steam engines or air jets from the safety valves of high pressure air tanks. The invention is applicable particularly to jet engine or rocket installations on aircraft, ships or land vehicles, in stationary plant or
 20 in ground testing installations.

The exhaust jet from a jet or rocket nozzle diverges in mixing with the atmosphere, the angle of divergence being dependent on the ratio of the pressure at the nozzle exit to the
 25 atmospheric pressure. When the jet exit velocity is greater than sonic velocity a train of shock waves will exist in the jet. The noise suppression means forming the subject of the present invention is applicable in cases where
 30 shock waves do and do not appear in the jet.

Experimental investigations have shown that the sound field produced by the jet is caused by the strong vorticity existing in the flow near to and beyond the nozzle exit.
 35 Thus, the coupling of eddying flow and large velocity gradients, whether lateral as in the mixing zone of the jet, or longitudinal as across shock waves, may give rise to intense
 40 noise. This sound field displays directional properties the character of which varies with the frequency of the noise produced and the jet speed at the nozzle exit.

The chief object of the present invention is to reduce the noise intensity over the complete frequency band as a result of a redistribution of this vorticity in the flow.
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As at present produced the jet or rocket exhaust nozzles of jet engine or rocket installations terminate in an annular ring or exit opening having a fixed boundary.
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The present invention consists broadly in providing means at the nozzle exit of a jet or rocket exhaust nozzle for modifying the jet boundary at the nozzle exit in such manner that the mixing region between the issuing gases and the atmosphere will be extended with a reduction in intensity of vorticity.
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Such means may, for example, take the form of an annular gauze or perforated metal cylinder or part of a cone arranged co-axially with the jet pipe and so arranged that it forms virtually an extension or part thereof. A proportion of the issuing gases will pass radially outwardly through the holes in the gauze or the like where it will mix with the atmosphere to reduce the intensity of the vorticity, the sound produced in the mixing region beyond the exit from the gauze or perforated cylinder being found by experiment to be less than that produced at the nozzle exit when the gauze or perforated cylinder was removed. During experiment the resistance of the gauze or perforated metal was adjusted by altering its length and porosity so that the nozzle excess pressure at the nozzle exit was dissipated over the length of the gauze component, the jet leaving the exit of the gauze component free from shock waves apart from weak disturbances created by the wires of the gauze or by the perforations in the metal. The outflow radially through the gauze is of low velocity compared with the jet efflux velocity and the sound energy produced by the flow inside the gauze component, which escapes through the gauze will be partially dissipated in its pores.
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Such a device is particularly suitable for use when the velocity of the jet at the nozzle exit is sonic and the pressure there is greater than in the atmosphere beyond the exit point from the gauze component. However, with such an arrangement there will be some noise reduction at lower jet velocities.
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Alternative means may take the form of a series of prongs attached to the nozzle exit so that they project rearwardly thereof. The number, length and width of the prongs as well as their geometric shape may be varied to suit the nozzle exit velocity. In addition some of the prongs may project inwardly inside the jet whilst others may project outwards or remain in line with the jet axis.
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As in the previously described arrangement the presence of the prongs will modify the jet boundary at the nozzle exit whilst the mixing region will be extended and the intensity of vorticity reduced. Hence the noise created in the jet will be less than that produced by the bare nozzle.
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The gauze, perforated metal components or the prongs may be applied to a jet nozzle of any cross-sectional shape. The prongs, if such are employed, instead of being fixed may be angularly adjustable and/or retract-
 115

able so that their angle relative to the jet axis is modified. In this way in addition to reducing the noise energy created by the jet, they may be used as a device for altering the jet exit area. The prongs may, for example, have a combined axial and angular movement under the control of electric, hydraulic or pneumatic actuators or some form of mechanical or other controlling mechanism

whereby their position can be varied as and when required. 10

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